

Experiments with
Westinghouse Gas Engine

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Westinghouse gas engine

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EXPERIMENTS
WITH
WESTINGHOUSE GAS ENGINE

A THESIS

PRESENTED BY

C. G. DREFFEIN
AND
I. J. TURNBULL

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

MECHANICAL ENGINEERING

JUNE, 1907 *ms*

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Experiments on Westinghouse Gas Engine.

In performing these experiments, the object was to determine the effect upon the economy of a gas engine when the heating value of the gas was lowered, other things being kept constant.

The engine used was a "Westinghouse" 8 x 10, three cylinder, vertical gas engine used for testing purposes in the laboratory at Armour Institute of Technology. This engine is of the single acting, four cycle type, with cranks at 120° . It is rated at 40 H.P., and runs at 325 r.p.m. The cylinders are independent, and are bolted upon the crank case, which is enclosed; the splash oil system being used for lubricating the cylinders, bearings on the connecting rods, and inside bearings on the crank shaft. The cylinder barrels and heads are water jacketed. All valves are mechanically operated by cams, and are held on their seats by springs.

Bolted to the crank case on either side, and opposite each crank, are cover plates about 12" x 15", which when removed give access to the interior. On each end of the case, and concentric with the main shaft are two large holes, into which the main bearing supports are bolted. The main bearings are in two sections, the wear being taken up by the lower section by means of the wedge and screws as shown. Since the thrust is always in one direction, downward, by taking up the wear with the one section the shaft is always kept in alignment. This is very important when the engine is direct connected to electrical machinery.



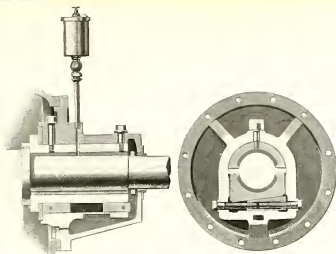


Fig. 7. Main Bearing



Crank Shaft of Three Cylinder Engine

As shown in the cut, the crank shaft has two inner bearings. These are provided with screws for adjustment in a lateral, and also with the wedges and screws, for the vertical direction. These are lubricated by the oil as it is splashed by the rods. The oil used in the crank case is a very heavy, mineral oil. The oil from the main bearings is drained into the crank case.

The connecting rods are of rectangular shape, and are fitted with the phosphor bronze bearings, as shown. Directly opposite the nuts on the upper end is a hole in the piston. When the piston is at its lower dead center, this hole is directly opposite a similar hole in the cylinder, which is plugged. By removing the plug, the wrist pin bearing can be properly adjusted





Fig. 8. Connecting Rod

by using the ordinary socket wrenches. When the rod is in its lowest position, the lower nut is in the oil bath. As the rod rotates, the projecting end of the one bolt strikes the oil first, causing it to "splash".

The pistons are of the long "trunk" type, and are fitted with four rings, three being above the wrist pin. These rings are of the ordinary split type, and are held against the cylinder wall by a split ring which is made in six sections, each section having a flat spring underneath it. The wrist pins have tapered ends, and are driven in.

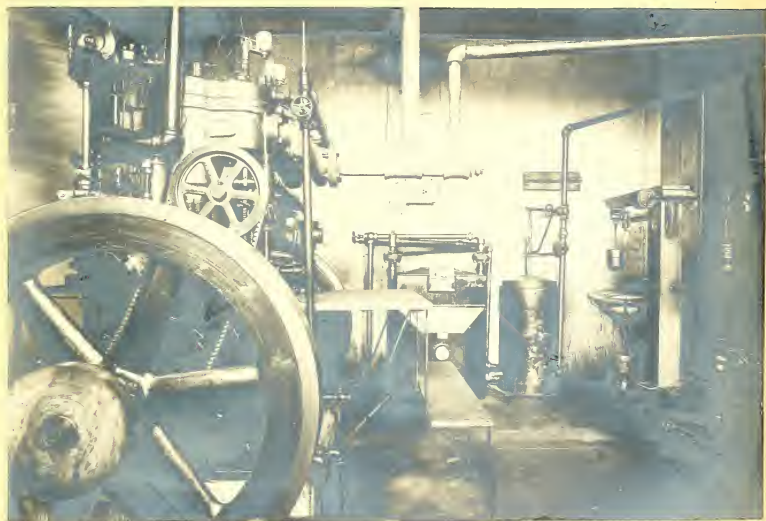


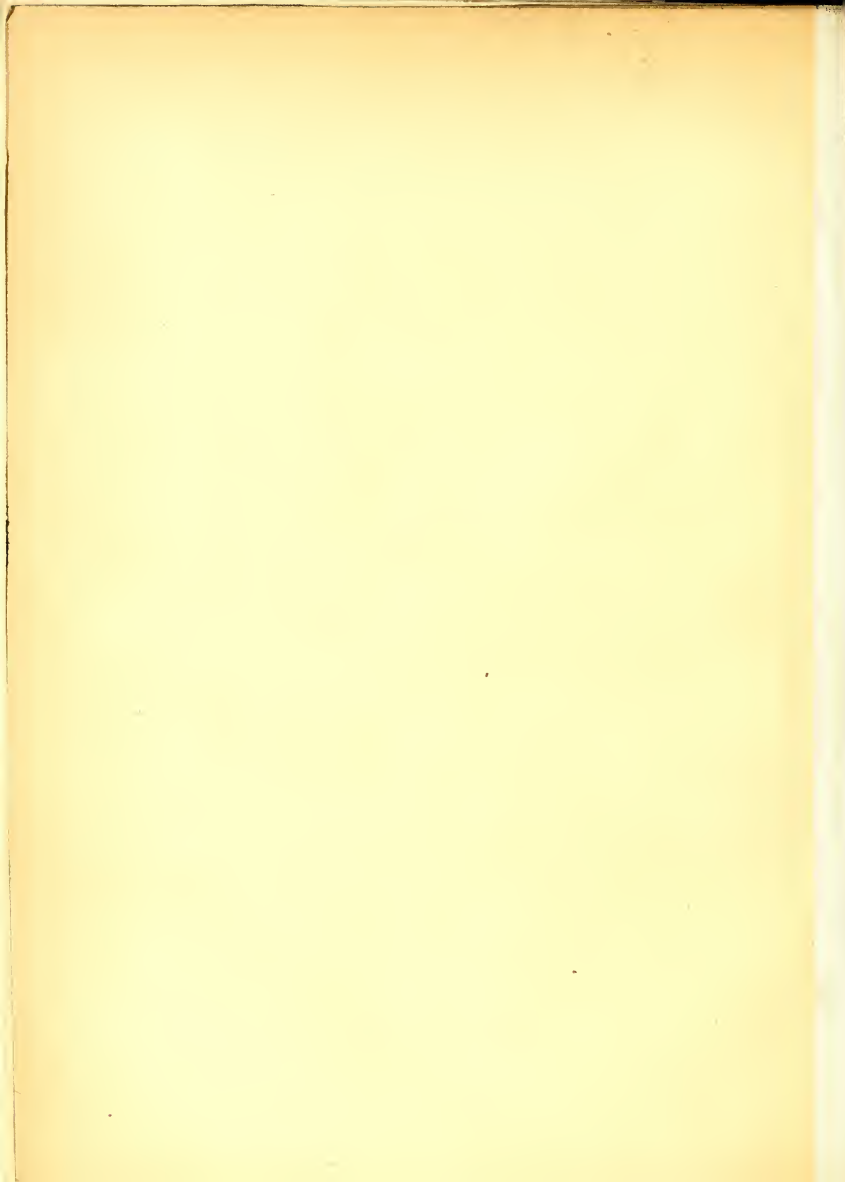
Fig. 9. Admission Valve

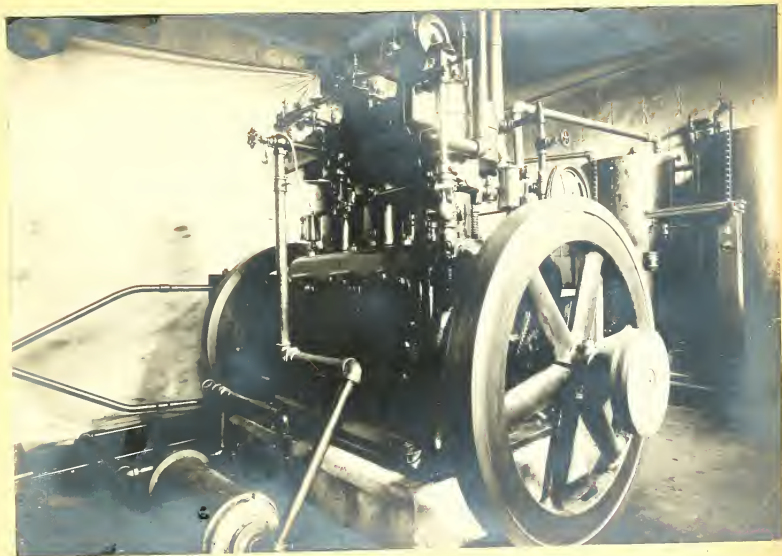
The valves are of the poppet type. The inlet valve seats on the end of a bonnet which is bolted to the head of the cylinder. The inlet valve stem, with its spring, is on top of the cylinder.

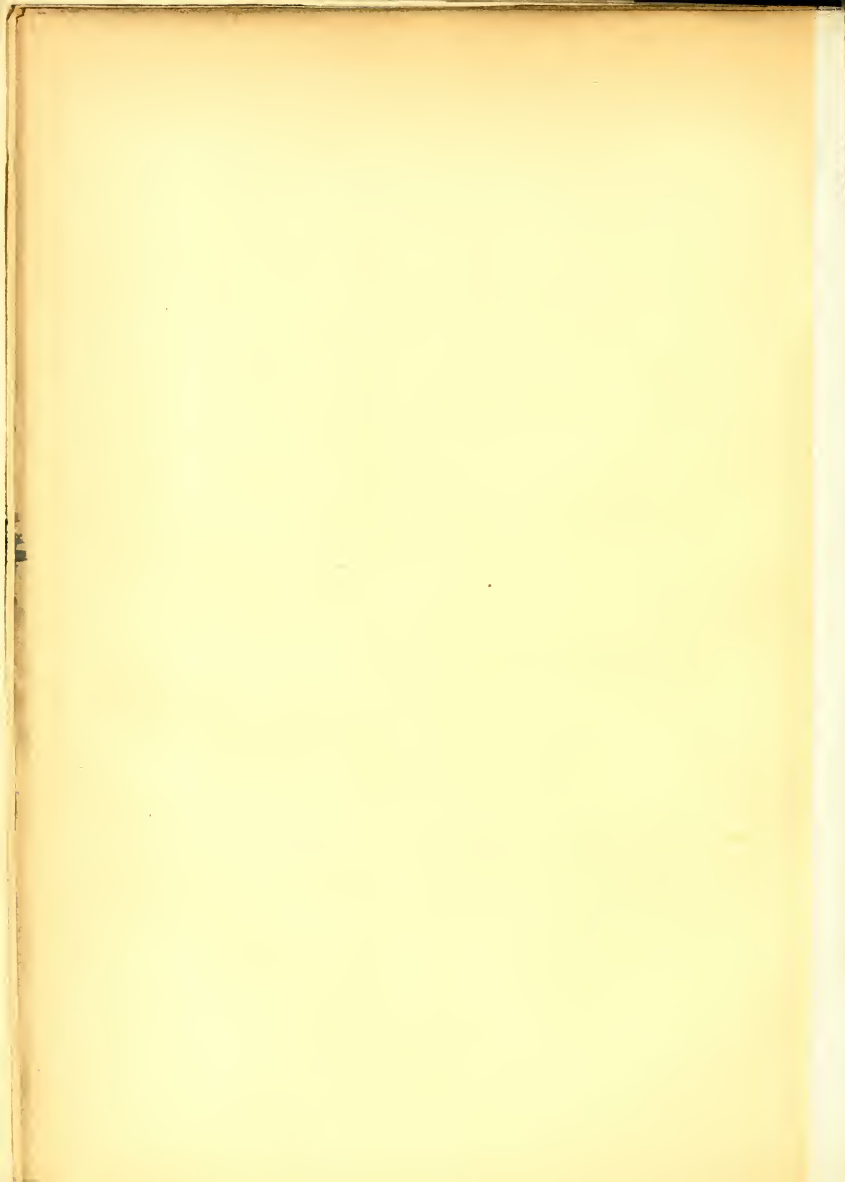
The exhaust valve is in the chamber to the rear of the cylinder at the top, and seats on a bushing

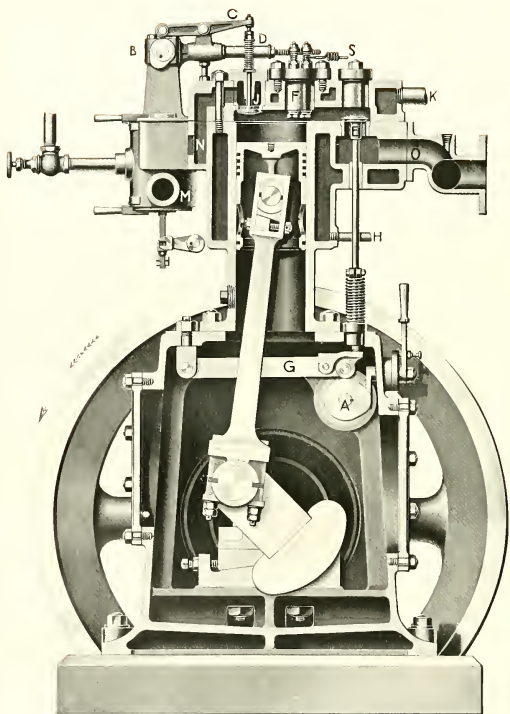












Cross Section through Cylinder

which can be renewed. The valve stem extends vertically downward.

Referring to the cut, "A", is the exhaust valve cam shaft. It is geared to the crank shaft by two to one gears, the gears being outside the crank case. The exhaust valve stem is made in two pieces, the lower being a pin about four inches long. There is a space of about 1/8th inch between the two sections, in which "liners" can be placed. By means of these "liners", the clearance between the two sections can be adjusted so that the valve can be "timed" correctly. The lower section passes thru a bushing and rests upon the pivoted lever, "G". This lever carries the cam roller, which is quite wide, and rolls on the exhaust cam. The upper end of the spring is attached to the valve stem, and the lower to the frame, so that it is always in tension, and acts to hold the valve on its seat.

The inlet cam shaft is connected to the exhaust cam shaft by a vertical and a horizontal shaft, each fitted with bevel gears. The governor is attached to the vertical shaft. One end of the rocker arm, "C", carries the roller which rides on the cam, while the other is fitted with a screw, the end of which engages the end of the inlet valve stem. The time at which admission occurs can be adjusted by means of this screw.

Fitted to the inlet valve cam shaft are the igniter cams. The igniters are of the "make and break" type. The current is supplied by storage batteries, and passes thru a spark coil. As seen in the cut, one of the igniter poles is

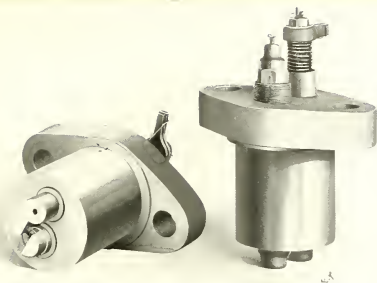


Fig. 10. Igniter

stationary, while the other can be rotated; with a spring on the movable pole tending to hold them together. At the end of the movable pole is a short lever, which is moved by a collar on the end of the horizontal plunger "D". The other end of the plunger is squared, and is held against the cam by a spring. At the point where ignition occurs, is a straight drop of about one-quarter inch on the cam, and in order to prevent damage if the engine should be turned backwards, the cam on its inside is fitted with a ratchet device so that it can always be turned backwards; but when turned forwards, the pawl and ratchet become operative.

In order to provide a means for changing the time of ignition, the cam itself is loose on the shaft. On one end of its hub are cut about 100 small teeth. A collar fitted on the shaft also has a similar number of teeth, and the cam is held against this collar by screws. By means of this arrangement,



the ignition can be changed about three degrees per tooth.

The gas enters the engine thru a mixing and regulating valve. Surrounding the mixing chamber are two sleeves, one above the other, each having ports cut into it. The gas enters the mixing chamber thru the upper sleeve, and the air thru the lower. The regulating valve is inside of these sleeves, and controls the amount of the mixture delivered to the engine. Each sleeve has attached to it a lever carrying a pointer, which moves over an arc so graduated that the relative proportions of gas and air are indicated, when the gas is at atmospheric pressure. The regulating valve has a shaft at its bottom, which is connected to the fly-ball governor thru a rock-shaft.

Attached to the back of the engine is a light shaft, which is geared to the main shaft by a noiseless toothed chain drive. At each cylinder is an eccentric, which operate vertical rods, at the upper end of which small horizontal rods are fixed, to which the indicator cord is attached.

This engine is provided with an automatic starter, by which one cylinder acts as a compressed air engine until explosions occur in the other cylinders. The exhaust cam shaft extends beyond the crank case, and is fitted with a cam. This cam acts upon the spindle of a valve in the compressed air pipe, and permits air to enter the left cylinder each revolution. This valve stem is fitted at its top with a milled head having two projections, so that by lifting and turning it thru 90 degrees, the stem clears the cam. In order to use this cylinder as

a compressed air engine, the cam controlling the inlet valve is so constructed that it is released and allowed to rotate freely upon the shaft,- by turning in a screw projecting thru from the end of the shaft, which is bored out at this end,- thus giving no admission of gas to the cylinder. When the engine has been started, this cylinder is put into operation by simply turning this screw out, thus engaging the cam.

In order that the engine will start easily, it is so arranged that the exhaust valves can be made to open each revolution. A collar which will move upon a sliding key-way, is provided beside each exhaust cam. This collar has a cam on it similar to the exhaust cam, but differing from it by 180 degrees. When a connecting lever, which projects thru the crank case, is shifted from its central position this collar is moved over against the exhaust cam, so that the roller which is wider than the exhaust cam, rides also on the auxiliary cam, thus opening the exhaust once per revolution.

Natural gas was used in these experiments. It was first passed thru a Westinghouse wet gas meter, from which it passed to the regulator. This regulator was of the diaphragm type, and the pressures could be adjusted so that it would be atmospheric at the engine. The gas then passes to the mixing chamber.

In order to lower the heating value of the gas, it was diluted with exhaust from the engine. At the end of the 3" exhaust pipe a 2" branch pipe was taken off. This pipe led to a cooling coil of 1-1/2" pipe placed in the weighing tank.



In order to calculate the size of the coil, the maximum amount of gas supplied per hour was assumed to be 500 cubic feet of 960 B.t.u. effective heating value per cubic foot; or 480,000 B.t.u. per hour. (The gas consumption of the engine at full load is about 12.5 cu.ft. per H.P. per hour.)

In performing these experiments it was thought best to use City gas for reducing the heating value to the lowest values, because less exhaust gas would be necessary. Hence, if the effective heating value of City gas is 650 B.t.u. per cubic foot,

$\frac{480,000}{650} = 740$ cu.ft. are necessary. The lowest heating value of the mixture was assumed to be 100 B.t.u. per cu.ft.

In order to reduce the heating value of the gas from 650 B.t.u. to 100 B.t.u., it must be diluted with 5.5 cubic feet of inert or exhaust gas. Hence,

$$5.5 \times 740 = 4,070 \text{ cu.ft. per hour, or}$$

$$1.13 \text{ cu.ft. per second, under standard conditions.}$$

Assume the temperature of the exhaust gas to be 900° at one pound back pressure. The volume of gas under these

$$\text{conditions is, } V_2 = \frac{P_1 V_1}{T_1} \cdot \frac{T_2}{P_2} = \frac{30 \times 1.13 \times 1560}{532 \times 32}$$

$$= 2.70 \text{ cu.ft. of exhaust gas per second.}$$

Since the area of a 2" pipe is .0141 sq.ft., the velocity of the gas would be $\frac{2.70}{.0141} = 116$ feet per second.

As the density of exhaust gas is approximately .11, the weight of exhaust gas = $.11 \times 1.13 = .1243$ # per second.

Assuming that the temperature of the gas leaving the coil is 80 degrees, the drop in temperature is 820 degrees. The



specific heat of exhaust gas is approximately .25 Then the heat which is necessary to be abstracted from the gas is,

$$.1243 \times .25 \times 820 = 25.5 \text{ B.t.u. per second.}$$

Assume the inlet cooling water temperature 45° , and the outlet 100° . Then the mean temperature difference is,

$$900 - 45 + \frac{- 820 - 55}{2} = 417 \text{ degrees.}$$

Assuming that the B.t.u. transmitted per square foot per hour, per degree difference in temperature is 10; the amount of radiating surface required, with a mean temperature difference of 417° is $\frac{25.5 \times 3600}{10 \times 417} = 22$ square feet. The external circumference of an $1\text{-}1/2"$ pipe is $5.97"$, therefore the length of $1\text{-}1/2"$ pipe required in the coil is $\frac{22 \times 12}{5.97} = 44$ ft.

The coil was made up of ten lengths of $1\text{-}1/2"$ pipe, each $46"$ long, fitted with right and left return bends, $3\text{-}1/2"$ centers. The total radiating surface of the coil was 42 square feet.

From the coil the gas passed to a gasometer $18"$ in diameter, of about 4 cubic feet capacity, and so arranged that it could be counterweighted. In the vertical pipe leading to the gasometer was a plug cock, which was connected to the gasometer thru a slotted lever. A globe valve was also located just above the plug cock. By means of these, a constant pressure was obtained in the gasometer. The gas then passed to a 150 light dry meter, where the temperature and pressure of the gas were taken at the inlet. From the meter the gas passed to the mixing chamber. This was a piece of $8"$ pipe, capped at its ends, in which was placed a series of baffle plates. Each



baffle was of circular shape, so as to fit closely into the pipe, with the exception of a segment which was cut out to form the passageway for the gases; these openings being placed alternately at the top and the bottom of the pipe. This was done so that there would be less danger of stratification of the gases. The baffles were spaced 3-1/4" centers, and were held in place by a 3/4" x 1-1/2" wooden strip along each side.

From this mixing chamber the mixture passed into the gas valve of the engine. By means of a manometer, the pressure of the gas entering the valve could be obtained. After making a few runs, it was found that not enough exhaust gas could be obtained, so that a valve was placed in the exhaust pipe. By means of this the amount was regulated.

Before making any runs on the engine we determined the clearance volumes; and adjusted all events of the stroke to take place as nearly as possible to the points at which the manufacturers found by experiment to give the best results.

To measure the clearance volumes we removed the igniter plug, turned the engine until the piston was towards the end of the compression stroke, poured in a sufficient quantity of water to more than fill the clearance, replaced the igniter plug, and opening the indicator cock turned the engine forward slowly past dead center, which forced the excess of water out thru the indicator cock; and after turning the engine forward far enough so that all of the water remaining was contained in the cylinder barrel, we removed the igniter plug and measured the height of



water. From this the clearance volume can be calculated, as the diameter of the cylinder is known.

To adjust the position of the different events of the stroke we first located on the fly wheel the upper dead center position of the piston for each cylinder, by means of the trammel point method. To do this the igniter plug is removed, the engine turned in a forward direction until the piston is near its upper dead center, its position measured by means of a scale, an arc drawn on the fly wheel face with the trammel from a reference mark on the floor, the engine turned forward until the piston is in the same position as before as shown by the scale, and a second arc drawn on the fly wheel face with the trammel. Then the dead center is located at a point midway between these two positions. The time of ignition, and the time of opening and closing of inlet and exhaust valves was then measured as follows,- the changes in adjustment being made as indicated in the description of engine construction,- all of the measurements being taken with reference to the angular position of the connecting rod.

For the time of ignition the engine was turned forward slowly until the horizontal plunger stem tripped. With the trammel an arc was then drawn on the fly wheel face, and the length of the portion of circumference from this position to the dead center position measured. From the total circumference, the value of one degree in inches of circumference is known, and the angular position of the event can then be easily calculated.

The points of opening and closing of exhaust valve were determined by twisting the valve stem back and forth by hand; when one can note the position at which the valve just begins to leave its seat in opening, or reseal in closing.

The time of opening and closing of the inlet valves was determined by noting the points at which the screw at the end of the operating rocker arm just touched the end of the valve stem in opening, and just parted at closing.

The points for opening of the exhaust valve, and closing of inlet valve are recorded with reference to the lower dead center; while the closing of exhaust valve, opening of inlet valve, and ignition, are recorded with reference to the upper dead center.

The timing of events as adjusted were as follows:

| | Left Cyl. #1. | Center Cyl. #2 | Right Cyl. #3 |
|---------------------|---------------|----------------|---------------|
| Clearance volume, % | 22.81 | 21.25 | 21.56 |
| Inlet opens, | 5.1° E. | 5.35° E. | 7.75° E. |
| Inlet closes, | 15.0° L. | 19.2° L. | 15.5° L. |
| Ignition, | 28.5° E. | 30.8° E. | 23.75° E. |
| Exhaust opens, | 33.8° E. | 25.5° E. | 30.4° E. |
| Exhaust closes, | 5.93° E. | 2.95° E. | 2.37° L. |

To adjust the oil level in the meter, the pressure was relieved from both sides by closing the valves, the manometer being noted to see that the pressure was equalized. Oil was then poured into the plug provided in one side of the meter, and allowed to overflow, when the plug was replaced. The meter was



then calibrated by connecting it in series with a new test meter, and the correction factor of 1.044 obtained.

The dead weight of the brake was determined by removing it from the brake wheel, supporting it on a rod so that it hung in a horizontal position, and noting the weight upon the scales. This was found to be 22#.

Using natural gas, runs were made varying the amount of brake horse power developed, from over-load to quarter-load; taking 30 minute runs at over-load, full-load, three-quarter, half, and quarter-load. The power was absorbed by a Prony brake running on a water cooled pulley. The brake arm was 5' - 3" long, supported by a strut; the load was measured by platform scales.

During each run the following readings were taken: both gas meters, the temperatures and pressures of the gases at the meters, temperatures of the inlet and outlet cooling water, the speed of the engine, and total load on the scales. Indicator cards were taken at five minute intervals from each of the cylinders. Stop cards were also taken with each run. It was found, however, that the indicator cards were of value only as showing the conditions of operation within the cylinders, and the relative amount of work as divided between them. An attempt to calibrate the indicator springs showed that results could not be expected to come within ten per-cent. For this reason the indicated horse power was not used in calculating any of the results.

The calorific value of the gas was determined, both before and after the runs, by means of a Junker calorimeter.



Two series of runs were then made, keeping the power developed constant,- in the first series at 37.4 h.p., and in the second series at 25.2 h.p.- and lowering the heating value of the gas by diluting it with varying amounts of exhaust gas.

At times some difficulty was experienced on account of the governing of the engine. As this was most noticeable at the time of varying the amount of inert gas admitted, and also of changing the load,- both of which affect the conditions of relative amounts of gas supply,- we considered that this was caused by the diluted gas being delivered to the engine before it was completely mixed.

Computation of results.

$$\text{The brake horse power developed} = \frac{2 \pi r N P}{33,000} = .001 N P$$

Where: N = Number of revolutions per minute.

P = Total load on the scales, minus the dead weight of the brake.

The amount of natural gas consumed, as shown on the log sheet, is the reading of the natural gas meter, multiplied by the correction factor, 1.044

The calorific value of the gas, total, was calculated from the Junker calorimeter determinations, and is equal to,

$$\frac{\text{-Lbs. water x } ^\circ\text{C x 1.8}}{\text{Cu.ft. gas burned x f}} \quad \text{Where } f = \text{factor to reduce the}$$

volume of gas to standard conditions at 62°F , and 30" mercury.

Effective heating value = Total heating value, minus

$$\frac{1,000 \times \text{Lbs. condensed steam}}{\text{Cu.ft. gas burned x f}}$$

The heating value of the mixture was calculated as follows:

The total cubic feet of mixture used equals the amount of the natural gas plus the amount of exhaust gas admitted. The total heat units going into the engine remain the same as tho no exhaust gas was used. Therefore the heating value of the mixture

$$= \frac{\text{Cu.ft. natural gas}}{\text{Cu.ft. of mixture}} \times \text{calorific value of the natural gas}$$

in B.t.u. per cubic foot.

The number of explosions per minute = $3/2 \times$ R.p.m., as there is an explosion every other revolution in each of the three cylinders.

$$\text{B.t.u./ B.h.p./ hr.} = \frac{\text{*Gas per hour} \times \text{Effective heating value}}{\text{Brake horse power}}$$

$$\text{Thermodynamic efficiency /B.h.p., \%} = \frac{2545}{\text{B.t.u./B.h.p./ hr.}}$$

From the data secured in making the runs with natural gas, curves were plotted showing the relation of: Gas per B.h.p. per hour; Heat units per B.h.p. per hour; and Thermodynamic efficiency, to the horse power developed.

For the series of runs in which the load was maintained constant at 37.4 h.p., and the heating value of the mixture varied, curves were plotted showing the relation of: Gas per B.h.p. per hour; Heat units per B.h.p. per hour; and Thermodynamic efficiency, to the calorific value of the mixture, B.t.u. per cubic foot.

The runs made using natural gas showed a decrease in heat consumption per B.h.p. hour with increase of load, from quarter-load to about full load: and an increase in heat consumption as the load was still further increased. The least

gas consumption was about 10,700 B.t.u. per B.h.p. per hour.

The thermodynamic efficiency increases quite rapidly from light load up to rated load, decreasing with further increase of load. The highest thermodynamic efficiency obtained was 23.5% at 38 horse power.

The series of runs made keeping the H.P. constant, and lowering the heating value of the mixture showed the least number of heat units per B.h.p. per hour when using the gas of lower heating value; the heat consumption increasing with increase of calorific value of the mixture up to 480 B.t.u. per cubic foot. As the mixture was increased in richness above this value, the heat consumption per B.h.p. decreased.

As follows from the above, the thermodynamic efficiency increased as the calorific value of the mixture was decreased from 480 B.t.u. per cubic foot.

In the cards taken when the gas of low heating value was being used, the ignition line slopes forward considerably, the top of the card being rounded and maintaining its height for some distance, showing that the rate of flame propagation is lowered, which in turn causes the gases to continue burning during a portion of the power stroke.

A very small number of runs were made, owing to lack of time. For that reason we have not sufficient data to warrant any extended conclusions.



MECHANICAL ENGINEERING LABORATORY.

Armour Institute of Technology.

Date, _____

| Number of Run. | MAY 13 | MAY 14 | MAY 22 |
|---|--------|--------|--------|
| Duration of test, min. | 20 | 30 | 30 |
| Gas consumed, cu.ft. | 175.6 | 311.0 | 269.5 |
| Exhaust gas consumed, cu.ft. | 296.5 | 474 | 300 |
| Heating value of gas) Total | 970.5 | 954 | 933 |
| B.t.u. / cu.ft.) Effective | 888 | 869.5 | 853 |
| Heating value of mixture, | 375 | 397 | 409 |
| *Gas per hour, cu.ft. | 506 | 586 | 535 |
| * Exhaust gas per hour, cu.ft. | 845 | 891 | 580 |
| Gas at meter, ins. water, | 3.75 | 3.1 | 3.3 |
| Ex. gas at meter, " " | .25 | 0 | .5 |
| Barometer, ins. mercury, | 29.05 | 29.05 | 29.42 |
| Gas at engine, ins. water, | — | — | 1.08 |
| Jacket water, (Inlet, F° | 45 | 44 | 49.5 |
| (Outlet, F° | 101. | 92 | 100.0 |
| Gas at meter, F° | 71.5 | 81. | 60. |
| Exhaust gas at meter, F° | 73. | 77.5 | 69.6 |
| Revolutions per minute, | 314 | 306 | 319 |
| Explosions per minute, | 470 | 460 | 479 |
| Builders' rating, H.P. | 40 | 40 | 40 |
| Actual brake h.p. H.P. | 38.6 | 37.6 | 32.85 |
| B.t.u. / B.h.p. / hr. | 11640 | 13570 | 13880 |
| *Cu.ft. gas per B.h.p. | 13.1 | 15.6 | 16.27 |
| Thermodynamic efficiency per b.h.p., per cent, | 21.85 | 18.75 | 18.36 |

* Gas volumes reduced to 62° F. and 30" mercury.



MECHANICAL ENGINEERING LABORATORY.

Armour Institute of Technology.

Date, MAY 20 1907.

| Number of Run. | 1 | 2 | 3 | 4 | 5 |
|--|-------|-------|-------|-------|-------|
| Duration of test, Min. | 30. | 30. | 30. | 30. | 30. |
| Gas consumed/hr. cu.ft. | 303 | 342 | 404.5 | 528. | 703. |
| Exhaust gas consumed, cu.ft. | | | | | |
| Htg. value of gas, Total, | 911 | 911 | 911 | 911 | 911 |
| B.t.u. / cu.ft. Effective, | 838 | 838 | 838 | 838 | 838 |
| Heating value of mixture, | | | | | |
| * Gas per hour, cu.ft. | 304 | 343.4 | 405.9 | 529. | 704.3 |
| * Exhaust gas per hour, cu.ft. | | | | | |
| Gas at meter, ins. water, | 3.9 | 4.2 | 3.9 | 3.3 | 3.3 |
| Ex. gas at meter, " " | | | | | |
| Barometer, ins. mercury, | 29.7 | 29.7 | 29.7 | 29.7 | 29.7 |
| Gas at engine, ins. water, | 0 | 0 | 0 | 0 | 0 |
| Jacket water, (Inlet, °F. | 49 | 47.4 | 48 | 47 | 48 |
| (Outlet, °F. | 103.7 | 103.0 | 105.4 | 99.2 | 100.5 |
| Gas at meter, °F. | 60 | 60 | 60 | 60 | 60. |
| Exhaust gas at meter, °F. | | | | | |
| Revolutions per minute, | 328 | 325 | 327 | 326 | 319.0 |
| Explosions per minute, | 492 | 488 | 491 | 489 | 479 |
| Builders' rating, H.P. | 40. | 40. | 40. | 40. | 40. |
| Actual brake h.p. H.P. | 10.16 | 20.45 | 30.4 | 40.1 | 47.2 |
| B.t.u. / B.h.p. / hr. | 25100 | 14600 | 11200 | 11030 | 12490 |
| * Cu.ft. gas per B.h.p. | 29.95 | 16.78 | 13.36 | 13.18 | 14.9 |
| Thermodynamic efficiency per B.h.p., per cent, | 10.13 | 17.43 | 22.7 | 23.07 | 20.4 |

* Gas volumes reduced to 62° F. and 30" mercury.



MECHANICAL ENGINEERING LABORATORY.

Armour Institute of Technology.

Date, MAY 24 1907.

| Number of Run. | 1. | 2. | 3. | 4. |
|--|-------------|-------|-------|-------|
| Duration of test, Min. | 30 | 30 | 30 | 30 |
| Gas consumed, cu.ft. | 287.5 | 332.5 | 296 | 253. |
| Exhaust gas consumed, cu.ft. | 139.5 | 274.8 | 390 | 539. |
| Htg. value of gas, Total, | 919 | 919 | 919 | 919 |
| B.t.u. / cu.ft. Effective | 841.5 | 841.5 | 841.5 | 841.5 |
| Heating value of mixture, | 567 | 460 | 363 | 270. |
| * Gas per hour, cu.ft. | 566 | 652 | 580 | 500 |
| * Exhaust gas per hour, cu.ft. | 274 | 539 | 764.5 | 1060. |
| Gas at meter, ins. water, | 3.5 | 3.1 | 3.1 | 3.55 |
| Ex. gas at meter, " " | .88 | .75 | .75 | 1.88 |
| Barometer, ins. mercury, | 29.5 | 29.5 | 29.5 | 29.5 |
| Gas at engine, ins. water, | -.5 | -1.5 | -1.5 | -2.0 |
| Jacket water, (| Inlet, °F. | 49.5 | 49.5 | 49.5 |
| | Outlet, °F. | 102. | 101.5 | 101.2 |
| Gas at meter, °F. | 65.7 | 67.0 | 67.6 | 66.2 |
| Exhaust gas at meter, °F. | 64.0 | 64.5 | 65.1 | 64.25 |
| Revolutions per minute, | 320 | 317 | 317 | 316 |
| Explosions per minute, | 480 | 476 | 476 | 474 |
| Builders' rating, H.P. | 40. | 40. | 40. | 40. |
| Actual brake h.p. H.P. | 37.75 | 37.4 | 37.4 | 37.3 |
| B.t.u. / B.h.p. / hr. | 12620 | 14680 | 13040 | 11280 |
| * Cu.ft. gas per B.h.p. | 15.0 | 17.43 | 15.5 | 13.4 |
| Thermodynamic efficiency per B.h.p., per cent, | 20.17 | 17.35 | 19.5 | 22.6 |

* Gas volumes reduced to 62° F. and 30" mercury.



MECHANICAL ENGINEERING LABORATORY.

Armour Institute of Technology.

Date, MAY 25 1907.

| Number of Run. | 1 | 2 | 3 | |
|---|-------|-------|-------|--|
| Duration of test, Min. | 30 | 30 | 20 | |
| Gas consumed, cu.ft. | 218 | 319.5 | 125.8 | |
| Exhaust gas consumed, cu.ft. | 375.5 | 184.7 | 55.1 | |
| Htg. value of gas, (Total, | 948 | 948 | 948 | |
| B.t.u. / cu.ft. (Effective, | 871 | 871 | 871 | |
| Heating value of mixture, | 321 | 560 | 607 | |
| * Gas per hour, cu.ft. | 422 | 630 | 359 | |
| * Exhaust gas per hour, cu.ft. | 723 | 351.5 | 156.3 | |
| Gas at meter, ins. water, | 3.9 | 3.25 | 3.8 | |
| EX, gas at meter, ins. water, | 2.63 | 3.13 | 3.0 | |
| Barometer, ins. mercury, | 29.4 | 29.4 | 29.4 | |
| Gas at engine, ins. water, | 0. | -.63 | 1.75 | |
| Jacket water, (Inlet, °F. | 500 | 50.1 | 49.6 | |
| (Outlet, °F. | 100.5 | 100.0 | 97.1 | |
| Gas at meter, °F. | 750 | 79.5 | 82.5 | |
| Exhaust gas at meter, °F. | 740 | 82.0 | 85.2 | |
| Revolutions per minute, | 325 | 322 | 325 | |
| Explosions per minute, | 488 | 483 | 488 | |
| Builders' rating, H.P. | 40 | 40 | 40 | |
| Actual brake h.p. H.P. | 25.35 | 25.1 | 25.3 | |
| B.t.u. / B.h.p. / hour, | 14500 | 21850 | 12380 | |
| * Cu.ft. gas per B.h.p. | 16.66 | 25.1 | 14.2 | |
| Thermodynamic efficiency per B.h.p., per cent, | 17.56 | 11.64 | 20.6 | |

* Gas volumes reduced to 62° F. and 30" mercury.

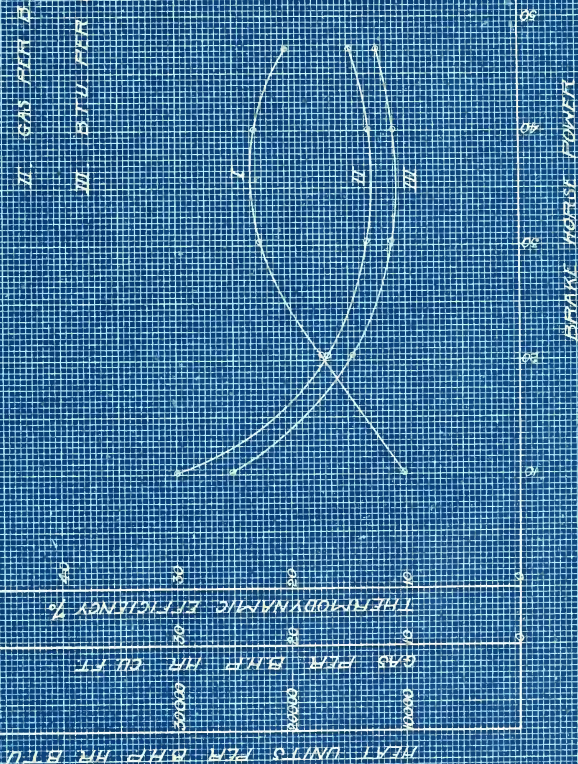


RUNS WITH NATURAL GAS

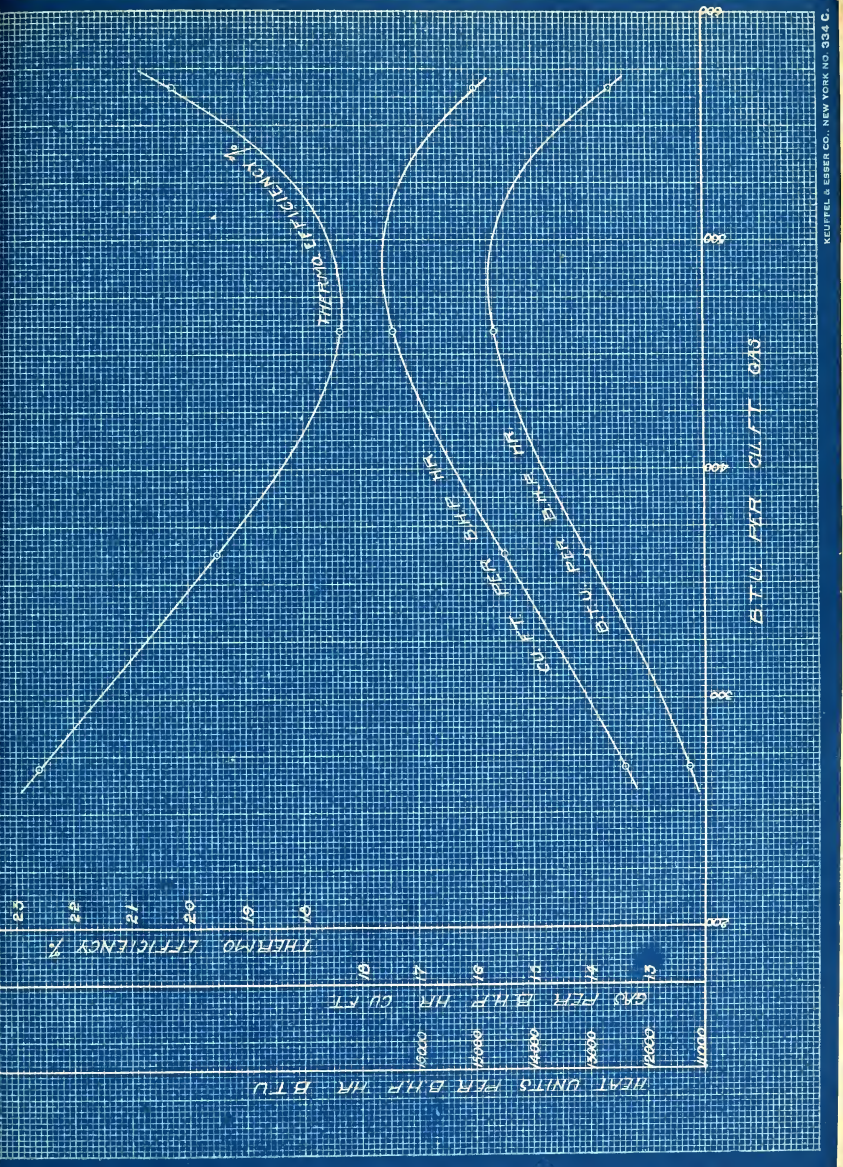
I. THERMODYNAMIC EFFICIENCY %

II. GAS PER BHP HR CU FT

III. BTU PER BHP HR







37.21

2

18

1-

50

5

11

11

.86



2000

40

2000

5

.88

(2.200)



#2

1-3

#3

#3

.80

3.00





RUNS MADE MAY 14 1907.

RUNS MADE WITH DILUTED GAS.

5-22-57

#

$$q = .65$$

$$L = 2.13$$

$$- = 2.1$$

$$\pm 1$$

$$.77$$

$$2.11$$



RUNS MADE WITH DILUTED GAS.

1-2: -3

102-97

* 2

$$L = .73$$

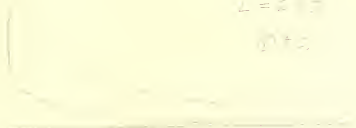
$$L = 2.82$$



$$L = .73$$

$$L = 2.82$$

$$L = 2.82$$



1-2: -3

$$L = .66$$

$$L = 2.82$$





$$\begin{aligned} \vec{r} &= r \hat{r} \\ &= r(\sin\theta \hat{e}_\theta + \cos\theta \hat{e}_\phi) \end{aligned}$$

$$\vec{r} \cdot \vec{r} = r^2$$

RUNS

WITH DILUTED GAS.

5-23-07

#3

$E = .74$

$\epsilon = 2.90$

200

100

5-24-07

1



RUNS MADE WITH DILUTED GAS.

(3) #

A =

L = 2.91

2 1/2

L

1.25

2.5

3.75

0.90

1.80

2.70

0.72

L

2.70

2.91

2.91

RUNS MADE WITH DILUTED GAS.

(3)

$$A = .73$$

$$B = .312$$

$$C = .150$$

$$D = .728$$

$$E = .55$$

$$F = .45$$

$$G = .15$$

$$H = .25$$

$$I = .15$$

$$J = .25$$

$$K = .15$$

$$L = .15$$



NS MADE WITH DILUTED GAS.

(3) = 2

$P = .71$

$L = 1.2$

1.2

(7) = 3

1.2

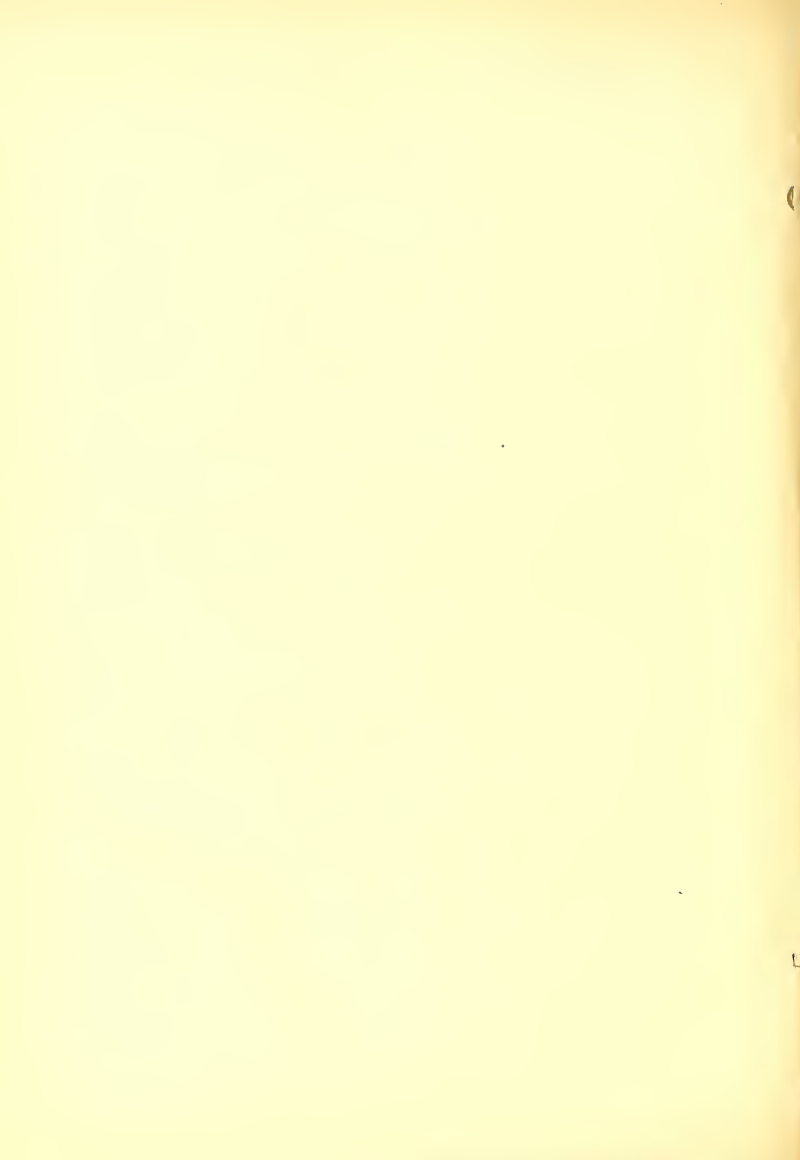


MADE WITH DILUTED GAS.

[Faint, illegible handwriting]

2/28

2/28



RUNS MADE WITH DILUTED GAS.

5-25
① #1

5-25

#1

$A = .51$

5-25
 $A = .55$
 $L = 2.9$
② #1

5-25 .25
 $A = .55$ 63
 $L = 2.9$ 79
② #2

5-25
 $A = .55$
 $L = 2.9$
③ #1

5-25
 $A = .55$
 $L = 2.9$
③ #2

25
}



RUNS MADE WITH DILUTED GAS.

5-25

#2

$$7 = .53$$

5-25 .25

$\bar{r} = .71$ 63

$\bar{r} = 2.1$ 79

② #2

5-25

$\bar{r} = .51$

$\bar{r} = 2.1$

③ #2

5

25



INS MADE WITH DILUTED GAS.

5-25

② #3

$$4 = .57$$

5-25

$$7 = .63$$

$$4 = 2.41$$

② #3

5-25

5-25

③ #3

25

1



MADE WITH DILUTED GAS.

5-25

(3)

5-25

(3)









